

THE ANALYZING POWER FOR THE $\bar{p}p \rightarrow pp\eta$ REACTION AT $Q = 10$ MeV¹

R. Czyżykiewicz^{2a,b}, P. Moskal^a, H.-H. Adam^c, A. Budzanowski^d, E. Czerwiński^a, D. Gil^a,
 D. Grzonka^b, M. Janusz^a, L. Jarczyk^a, B. Kamys^a, A. Khoukaz^c, K. Kilian^b, P. Klaja^a,
 B. Lorentz^b, J. Majewski^{a,b}, W. Oelert^b, C. Piskor-Ignatowicz^a, J. Przerwa^a, J. Ritman^b,
 H. Rohdjess^e, T. Rożek^{b,f}, R. Santo^c, T. Sefzick^b, M. Siemaszko^f, J. Smyrski^a,
 A. Täschner^c, K. Ulbrich^e, P. Winter^{b†}, M. Wolke^b, P. Wüstner^g, Z. Zhang^b, W. Zipper^f

^aInstitute of Physics, Jagellonian University, 30-059 Cracow, Poland

^bIKP, Forschungszentrum Jülich, 52425 Jülich, Germany

^cIKP, Westfälische Wilhelms-Universität, 48149 Münster, Germany

^dInstitute of Nuclear Physics, 31-342 Cracow, Poland

^eInstitut für Strahlen- und Kernphysik, Rheinische Friedrich-Wilhelms-Universität
 53115 Bonn, Germany

^fInstitute of Physics, University of Silesia, 40-007 Katowice, Poland

^gZEL, Forschungszentrum Jülich, 52425 Jülich, Germany

[†]present address: Paul Scherrer Institute, 5232 Villigen, Switzerland

Received 14 December 2005, in final form 8 March 2006, accepted 14 March 2006

The analyzing power A_y for the $\bar{p}p \rightarrow pp\eta$ reaction has been determined at the beam momentum $p_{beam} = 2010$ MeV/c, corresponding to the excess energy $Q = 10$ MeV. In the paper the method of the data analysis is briefly presented.

PACS: 14.40.-n, 13.60.Le, 14.40.Aq

1 Introduction

The close-to-threshold measurements of the total cross section for the $pp \rightarrow pp\eta$ reaction [1–6], the measurements of the differential cross sections [7–9], the high statistic investigations of the $pp\eta$ final state dynamics [10,11] as well as the results of the first ever analyzing power experiment for the $\bar{p}p \rightarrow pp\eta$ reaction [12] are in agreement with the hypothesis that the main contribution to the production of the η meson in the proton-proton collisions comes from the mesonic excitation of the $S_{11}(1535)$ resonance and its further decay into the $p\eta$ pair [13,14], as depicted in Fig. 1. However, it is still not settled what are the relative contributions to the production mechanism originating from each meson exchange denoted in Fig. 1. A possible way for elucidation of this problem is a precise measurement of the polarization observables, as they are very sensitive to the model assumptions on the type of the meson being exchanged in order to excite the S_{11}

¹Presented at the Workshop on Production and Decay of η and η' Mesons (ETA05), Cracow, 15–18 September 2005.

²E-mail address: r.czyzykiewicz@fz-juelich.de

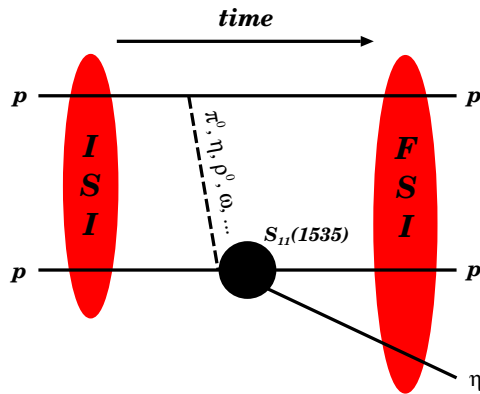


Fig. 1. The Feynman diagram for one of the possible explanations of the η meson production in elementary proton-proton collisions. ISI and FSI stand for the initial and final state interactions, respectively.

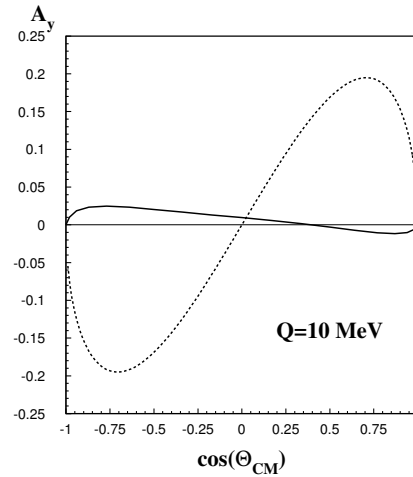


Fig. 2. Predictions of the analyzing power for the $\bar{p}p \rightarrow pp\eta$ reaction at $Q=10$ MeV as a function of the center-of-mass (CM) polar angle of η (θ_{CM}). Full line are the predictions of the pseudoscalar meson exchange model [15], whereas the dotted line represents the results of the calculations, based on the vector meson exchange [13].

resonance. For example, from Fig. 2, where the predictions of the analyzing power for the $\bar{p}p \rightarrow pp\eta$ reaction at the excess energy $Q = 10$ MeV are shown, it can be noticed that the analyzing power function strongly depends on whether we deal with pseudoscalar [15] (full line) or vector meson exchange model [13] (dotted line).

Therefore, in order to verify the validity of these two models, an experiment devoted to a determination of the analyzing power for the $\bar{p}p \rightarrow pp\eta$ reaction has been performed at the storage ring COSY in the Research Center Jülich in Germany. In this article we present preliminary results obtained at excess energy $Q = 10$ MeV, where the predictions of the models differ at most.

2 Experimental method

In the measurements a polarized proton beam [16, 17] has been used with the momentum of $p_{beam} = 2010$ MeV/c. This beam momentum value corresponds to the excess energy $Q=10$ MeV. The beam of protons has been scattered on the H_2 clusters, which were produced by the hydrogen cluster target [18]. The COSY-11 detection setup [19, 20] has been used for the detection of the reaction products.

As the COSY-11 system is a one-arm detection setup, in order to register both types of events: scattered to the right and to the left side (with respect to the polarization plane) there is a need to perform the experiment with the separate cycles, in which the spin of the proton beam has

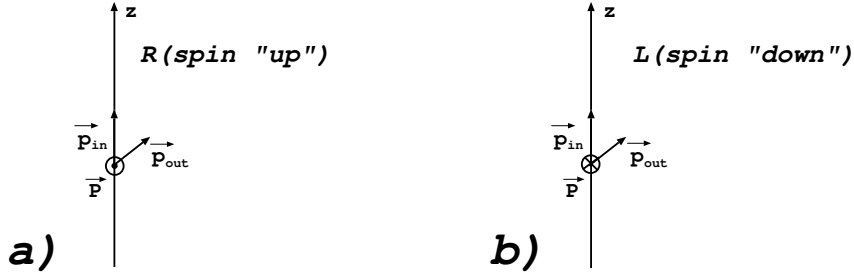


Fig. 3. Definition of the scattering to the right (a) and to the left side (b) with respect to the polarization plane. \vec{P} is a polarization vector of the beam of protons, whereas \vec{p}_{in} and \vec{p}_{out} denote the momenta of incoming and outgoing particles, respectively. The polarization vector of Fig. 3a points out of the paper, whereas the polarization vector of Fig. 3b points into the paper.

to be flipped, as schematically shown in Fig. 3. In this figure we also define what is meant by the terms: "scattering to the right" and "to the left". This definition strictly follows the Madison convention [21].

In the following we define the polarization plane as a plane spanned by the beam momentum vector $\vec{p}_{beam} \equiv [0, 0, p_{beam}^z]$ and a polarization vector $\vec{P} = [0, P, 0]$. If the incident beam consists of spin $\frac{1}{2}$ particles with a transverse polarization, which was the case in our experiment, the formula for the differential cross section $\sigma(\theta, \phi)$ for a scattering into the solid angle around θ and ϕ angles reads:

$$\sigma(\theta, \phi) = \sigma_0(\theta)(1 + A_y(\theta)\vec{P} \cdot \hat{n}), \quad (1)$$

where $\sigma_0(\theta)$ denotes the differential cross section for a scattering of an unpolarized beam, $A_y(\theta)$ is an analyzing power of the reaction, and \hat{n} is a unit vector along $\vec{p}_{in} \times \vec{p}_{out}$. ϕ is an angle between \vec{P} and \hat{n} , i.e. $\vec{P} \cdot \hat{n} = P \cos \phi \sin \theta$ and θ denotes the angle between \vec{p}_{in} and \vec{p}_{out} . In the experiment we were restricted to the plane corresponding to $\phi = 0^\circ$ in case of spin "down" (or $\phi = 180^\circ$ for spin "up"), where the detection efficiency of the COSY-11 setup is the highest and it decreases drastically when going outside this particular scattering plane (see Fig. 4). Therefore, in what follows we will consider the scattering in this plane solely.

The total production rate to the right N_R and to the left side N_L can be expressed as follows:

$$\begin{aligned} N_R(\theta) = N(\theta, \phi = \pi) &= \sigma_R(\theta, \pi)E_R(\theta, \pi) \int L_R dt_R \\ &= \sigma_0(\theta)(1 - A_y(\theta)P_R)E_R(\theta, \pi) \int L_R dt_R, \end{aligned} \quad (2)$$

$$\begin{aligned} N_L(\theta) = N(\theta, \phi = 0) &= \sigma_L(\theta, 0)E_L(\theta, 0) \int L_L dt_L \\ &= \sigma_0(\theta)(1 + A_y(\theta)P_L)E_L(\theta, 0) \int L_L dt_L, \end{aligned} \quad (3)$$

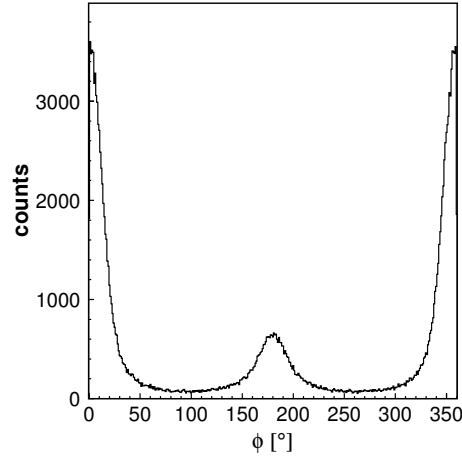


Fig. 4. Monte-Carlo simulation of the distribution of the events as a function of the angle ϕ .

where the $E_R(\theta, \pi) \equiv E_L(\theta, 0)$ is the function of the efficiency of the COSY-11 detection system, $L_{R/L}$ stands for the luminosity for spin up/down, and $t_{R/L}$ denotes the time of the measurement with spin up/down, respectively. The polarization degrees P_R for spin up and P_L for spin down are equal within the 5% of accuracy, as has been shown in the previous measurements by means of the EDDA polarimeter [22]. Therefore for the further considerations we will assume that $P_L = P_R \equiv P$. Dividing equation 3 by 2, and introducing a relative luminosity:

$$L_{rel} \equiv \frac{\int L_R dt_R}{\int L_L dt_L}, \quad (4)$$

results in the following formula for the analyzing power:

$$A_y(\cos \theta) = \frac{1}{P} \frac{L_{rel} N_L(\cos \theta) - N_R(\cos \theta)}{L_{rel} N_L(\cos \theta) + N_R(\cos \theta)}, \quad (5)$$

Therefore, the values of the relative luminosity L_{rel} , the spin-averaged polarization degree P , together with the production rates to the right N_R , and to the left side N_L are the physical observables to be found in order to determine the analyzing power function A_y . In the following subsections the methods used to obtain these quantities will be presented.

2.1 Calculations of the relative luminosity and polarization

The experiment has been performed with the 300 s long cycles, for which the spin of the incident proton beam has been flipped from cycle to cycle. This method was intended to reduce the systematical uncertainties caused by the change of the beam parameters due to the variation of the target densities. The duration of the cycle has been set up in such a manner, that it was significantly shorter than the time scale (10 hours) for the substantial changes of the density of the target.

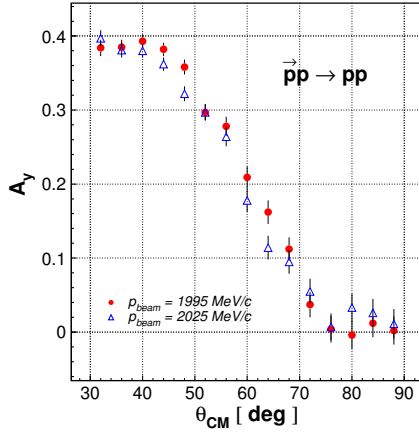


Fig. 5. Analyzing powers for the $\vec{p}p \rightarrow pp$ elastic scattering as determined by the EDDA collaboration [22] at the beam momenta specified inside a figure. To obtain the analyzing powers for a beam momentum used in the experiment a linear approximation has been applied.

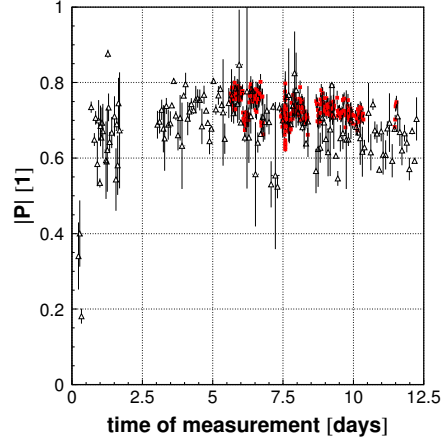


Fig. 6. Average polarization degree versus the time of the measurement. Open circles are the results obtained by means of the COSY polarimeter, whereas the full dots are the polarization values determined using the method described in [23]. Data obtained using the independent methods are in line.

For the determination of the relative luminosity a detection system consisting of two pairs of the scintillators placed in the polarization plane have been used [23]. Due to the parity invariance, a cross section for any scattering into this plane does not depend on the polarization degree. Thus, the number of the coincidences n between scintillators has been used as a measure of the absolute luminosity. Following the definition given in eq. 4, we can express the relative luminosity as a ratio of the number of coincidences in the polarization plane during the cycles with spin "up" (n_R) and "down" (n_L):

$$L_{rel} = \frac{n_R}{n_L}. \quad (6)$$

The relative luminosity determined using eq. 6 was found to be $L_{rel} = 0.96468 \pm 0.00065$.

The detailed method of determination of the averaged polarization value has been described in [23]. For the calculations the asymmetry of the elastically scattered events in the plane perpendicular to the polarization plane has been found for different scattering angles in the center-of-mass system (CM). In order to determine the values of the analyzing powers for the beam momentum of $p_{beam} = 2010$ MeV, the linear interpolations between available experimental results for the proton-proton elastic scattering at $p_{beam} = 1995$ and 2025 MeV/c have been used. Two data sets of the analyzing powers for the $\vec{p}p \rightarrow pp$ reaction for the mentioned above beam momenta, as measured by the EDDA collaboration [22] at different CM scattering angles, are presented in Fig. 5.

Fig. 6 depicts the variation of the beam polarization during the time of the measurement. Data sets obtained using the COSY polarimeter [24] (open circles) are confronted with the results of

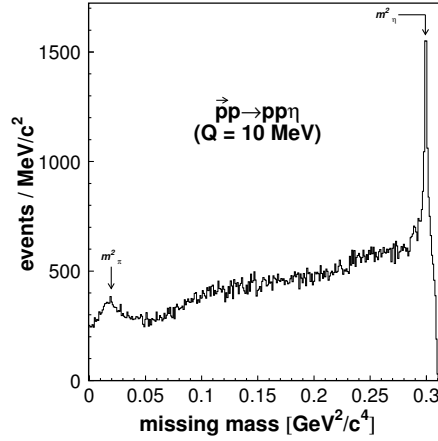


Fig. 7. Spin-averaged missing mass spectrum for the $\bar{p}p \rightarrow pp\eta$ reaction at the excess energy $Q = 10$ MeV, as measured by means of the COSY-11 detector setup.

the measurements with the COSY-11 polarimeter [23,25,26](full circles). An agreement between both sets of data is visible in Fig. 6. The average value of the beam polarization for the whole period of the measurement was found to be $P=0.680 \pm 0.010$.

2.2 Determination of the background free production rates for the $\bar{p}p \rightarrow pp\eta$ reaction

A typical missing mass spectrum for the $\bar{p}p \rightarrow pp\eta$ reaction as measured using the COSY-11 detection setup is presented in Fig. 7. Figure shows the spin-averaged missing mass spectrum, gathered during the whole time of the experiment. Over the wide multi-pionic background a clear peak originating from the η meson production is visible.

Optimizing the statistics and the expected shape of the analyzing power function, the range of the center-of-mass polar angles of the η meson emission has been divided into four bins. To separate the actual production rates from the background, the reactions with multi-pionic production as well as the events with η production have been simulated, using a program based on the GEANT3 [27] code. Generated events which fulfilled conditions equivalent to the experimental trigger have been analyzed in the same way as the experimental data. In such a way we have obtained the missing mass shapes of the background reactions ($pp \rightarrow pp2\pi, 3\pi, 4\pi$) as well as the shape of the signal ($pp \rightarrow pp\eta$). In order to perform credible simulations of the missing mass spectra the geometry of the drift chambers (used for the momentum reconstruction) as well as the position and geometrical parameters of the target have to be known precisely. The angle and the relative position of the COSY-11 drift chambers (2 parameters), a target position (3 parameters) and a relative shift between the beam and a target (1 parameter) have been optimized using the elastically scattered events and the method described in [11, 29].

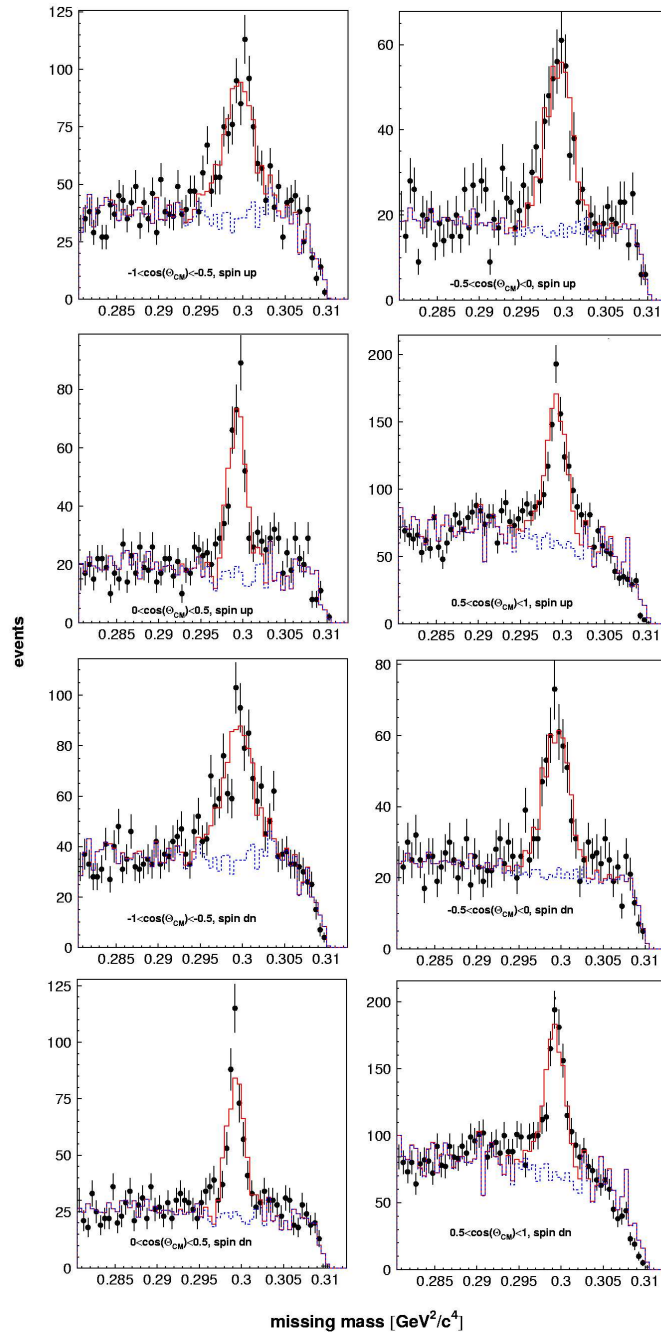


Fig. 8. Missing mass spectra for different ranges of $\cos \theta_{CM}$ for spin up (two upper panels) and spin down (two lower panels). Dots represent the experimental points. Dotted line shows the generated multi-pionic background. The full line is a best fit of the sum of the signal and background to the experimental data.

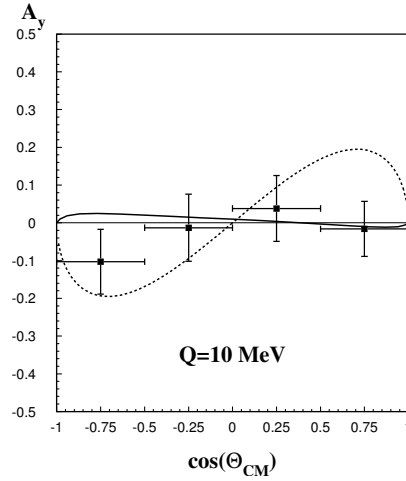


Fig. 9. Preliminary analyzing power function for the $\bar{p}p \rightarrow pp\eta$ reaction at $Q=10$ MeV. Vertical bars denote the statistical error, whereas the horizontal bars stand for the ranges of averaging.

The multi-dimensional fit of the simulated missing mass spectra to the corresponding experimental histograms has been performed using the MINUIT [28] minimization package. The fit has been performed simultaneously to 8 histograms (see Fig. 8), each with 60 points. The χ^2 of the fit have been minimized as a function of six parameters: scaling factors of the generated background and signal reactions (altogether 4 parameters) and 2 parameters responsible for the spread and the absolute value of the beam momentum. The detailed process of the search for the best values of these parameters will be described elsewhere [30], here we would only like to report that the minimum value of χ^2 was found to be 1.62, corresponding to the spread of the beam momentum equal to 0.2 MeV/c and the shift from the nominal beam momentum equal to 2.1 MeV/c. These values are in a good agreement with results of previous COSY-11 experiments [29].

In Fig. 8 the missing masses for the individual θ_{CM} subranges, separately for spin up (upper panel) and down (lower panel), are shown. Full dots correspond to the experimental data, the dotted line depicts the shape of the background, whereas the solid line represents the best fit of the Monte-Carlo data to the experimental spectra.

3 Results

Preliminary results of the analyzing power function $A_y(\cos\theta)$ are presented in Fig. 9 as the full dots. The dotted line shows the predictions determined according to the vector meson exchange model [13], whereas the solid line refers to the pseudoscalar meson exchange model [15]. The errors are of the statistical nature only.

4 Conclusions

The preliminary analyzing power results are bared with rather large statistical uncertainties, therefore a statement on the mechanism of the η meson production relying on this set of data is currently unclear. As can be seen from Fig. 9 the data point at $\cos\theta = 0.75$ tend to prefer the pseudoscalar meson exchange model [15], whereas the data point at $\cos\theta = -0.75$ is slightly more in line with the predictions of the vector meson exchange model. The results show rather small values of the analyzing power in the close-to-threshold region, which may be the indication of the η production to the s -wave final state, solely. However, for this statement the exact partial wave analysis remains to be done.

Acknowledgement: We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (Hadron-Physics, contract number RII3-CT-2004-506078), of the FFE grants (41266606 and 41266654) from the Research Centre Jülich, of the DAAD Exchange Programme (PPP-Polen), of the Polish State Committee for Sci. Res. (grant No. PB1060/P03/2004/26), and of the RII3/CT/2004/506078 - Hadron Physics-Activity -N4:EtaMesonNet.

References

- [1] A.M. Bergdolt et al.: *Phys. Rev. D* **48** (1993) 2969
- [2] E. Chiavassa et al.: *Phys. Lett. B* **322** (1994) 270
- [3] H. Calén et al.: *Phys. Lett. B* **366** (1996) 39
- [4] H. Calén et al.: *Phys. Rev. Lett.* **79** (1997) 2642
- [5] F. Hibou et al.: *Phys. Lett. B* **438** (1998) 41
- [6] J. Smyrski et al.: *Phys. Lett. B* **474** (2000) 182
- [7] H. Calén et al.: *Phys. Lett. B* **458** (1999) 190
- [8] B. Tatischeff et al.: *Phys. Rev. C* **62** (2000) 054001
- [9] M. Abdel-Bary et al.: *Eur. Phys. J. A* **16** (2003) 127
- [10] P. Moskal et al.: *Phys. Rev. C* **69** (2004) 025203
- [11] P. Moskal: *Hadronic interaction of η and η' mesons with protons*, Habilitation Dissertation No. 364, Jagellonian University Press (2004); e-Print Archive: hep-ph/0408162
- [12] P. Winter et al.: *Phys. Lett. B* **544** (2002) 251 ; erratum-ibid. **553** (2003) 339
- [13] G. Fäldt, C. Wilkin: *Phys. Scripta* **64** (2001) 427
- [14] C. Hanhart: *Phys. Rept.* **397** (2004) 155
- [15] K. Nakayama et al.: *Phys. Rev. C* **65** (2002) 045210
- [16] D. Prasuhn et al.: *Nucl. Instr. & Meth. A* **441** (2000) 167
- [17] H. Stockhorst: *Polarized Proton and Deuteron Beams at COSY in the Proceedings of the second symposium on threshold meson production in pp and pd interaction*, ed. P. Moskal; Schriften des Forschungszentrum Jülich, Matter and Materials **21** (2004) pp. 106-121; e-Print Archive: physics/0411148
- [18] H. Dombrowski et al.: *Nucl. Instr. & Meth. A* **386** (1997) 228
- [19] S. Brauksiepe et al.: *Nucl. Instr. & Meth. A* **376** (1996) 397
- [20] J. Smyrski et al.: *Nucl. Instr. & Meth. A* **541** (2005) 574

- [21] Madison Convention, in *Polarisation Phenomena in Nuclear Reactions*, University of Wisconsin Press, Madison (1971) pp. XXV
- [22] M. Altmeier et al.: *Phys. Rev. Lett.* **85** (2000) 1819
- [23] R. Czyżykiewicz: *COSY-11 as a polarimeter* in the *Proceedings of the second symposium on threshold meson production in pp and pd interaction*, ed. P. Moskal; Schriften des Forschungszentrum Jülich, Matter and Materials **21** (2004) pp. 122-137
- [24] F. Bauer and K. Büsser: *Nucl. Instr. & Meth. A* **431** (1999) 385
- [25] I.-A. Pellmann: Diploma Thesis (1999), Berichte des FZ-Jülich, Jül-3686.
- [26] P. Kowina et al.: contribution to the *Annual Report of IKP* (2001) pp. 14, Berichte des FZ-Jülich, Jül-3978
- [27] GEANT — Detector Description and Simulation Tool, CERN Program Library Long Writeups W5013 (1994)
- [28] MINUIT — Minimization Package, CERN Program Library Long Writeups D506 (1994)
- [29] P. Moskal et al.: *Nucl. Instr. & Meth. A* **466** (2001) 448
- [30] R. Czyżykiewicz: PhD Dissertation at the Jagellonian University, in preparation